Plant Protection Bulletin 39: 207~225, 1997

Biological Control of Turf Diseases Using *Trichoderma harzianum*

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(Accepted for publication: July 15, 1997)

ABSTRACT

Lo, C. T. 1997. Biological control of turf diseases using *Trichoderma harzianum*. Plant Prot. Bull. 39: 207-225.

Pythium blight and root rots caused by *Pythium aphanidermatum* and *P. graminicola*, brown patch caused by *Rhizoctonia solani*, and dollar spot caused by *Sclerotinia homoeocarpa* are the most common diseases on golf course turf and home lawns. Recently, *Trichoderma harzianum* Rifai has received much attention because of its potential as a biocontrol agent of various phytopathogenic fungi. *T. harzianum* strain 1295-22 is a commercially available biocontrol agent that is highly rhizosphere competent and able to control several crop diseases including turfgrass. Based on field results, the strategies for effective control Pythium root rot, Rhizoctonia brown patch, and Sclerotinia dollar spot of turfgrass using *T. harzianum* strain 1295-22 are to apply granules in the spring to create disease-suppressive soils and possibly enhance plant vigor. This granular application should be followed by monthly spray applications to suppress foliar phases of these diseases. In addition, it will be necessary to apply weekly sprays for highly effective control of these diseases under severe disease situations.

(Key words: biological control, turfgrass diseases, *Trichoderma harzianum*, delivery system)

INTRODUCTION

Turfgrass diseases may be caused by fungi, bacteria, viruses, nematodes, or phytoplasmas[88]. Over 90% of diseases are caused by fungi[81,88]. Pythium blight and root rots caused by *Pythium aphanidermatum* (Edson) Fitzp. and *P.*

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graminicola Subramanian, brown patch caused by *Rhizoctonia solani* Kühn, and dollar spot caused by *Sclerotinia homoeocarpa* F. T. Bennett are among the most common diseases on golf course turf and home lawns in the United States(39,67,81). Typically, control of these diseases on golf course turf is achieved by repeated applications of fungicides(76). However, numerous applications of broad spectrum or persistent chemicals may result in soil contamination, fungicide resistance, or other harmful nontarget effects(63). There has been a significant increase over the past few years in the amount of fungicides used in turfgrass management(81). Consequently, the development of non-toxic alternatives to chemical fungicides for control of these diseases would be very useful in reducing non-desirable environmental effects and human exposure to pesticides.

Biological control potentially can be a non-toxic alternative to chemical fungicides and can reduce fungicide applications to highly managed golf course turf. Recent studies suggest that applications of individual microbes are capable of reducing the severity of turfgrass diseases(13,14,51,59,61,81). To our knowledge, however, only one of those biocontrol agents is commercially available.

T. harzianum Rifai has received much attention because of its potential as a biocontrol agent of many plant pathogenic fungi(69). Recent studies have shown that *T. harzianum* strain 1295-22 is a highly rhizosphere-competent biocontrol microbe (78) that was produced by protoplast fusion between two strains of *T. harzianum*(50,85) and has been registered with the U. S. Environmental Protection Agency for a range of crops, including turfgrass(46,61). Strain 1295-22 may thus be used to control soilborne fungal diseases of turfgrass(60). It is available commerically as Bio-Trek 22G and is sold by Wilbur-Ellis Co., Fresno, CA, and manufactured by BioWorks Inc., Geneva, NY.

Successful biocontrol requires an understanding of several factors including the cropping system; epidemiology of the diseases to be controlled; the biology, ecology, and population dynamics of the biocontrol organisms; and the interactions among these variables(1,84). The turfgrass ecosystem is quite different from crop agroecosystems. It contains a dense foliar canopy that is continuously wounded by frequent mowing and can remain wet for extended periods of time. This creates a favorable environment for pathogens to spread from plant to plant(95). Many turfgrass pathogens, such as *Pythium* spp. and *Rhizoctonia* spp., can attack blades of grass and spread aerially from blade to blade(81). Biocontrol agents differ fundamentally from chemical fungicides in that they must grow and proliferate to be effective(21). The effective antagonists must become established in turfgrass ecosystems and remain active against target pathogens during periods favorable for plant infection (66). Consequently, the biological and ecological traits of biocontrol agents in turfgrass ecosystems must be understood, and methods of application should be developed for effective control of turfgrass diseases. In this article I will discuss (a)the cultivation species, (b)growth conditions and turfgrass susceptibility to pathogens, (c)

the problems of chemical control associated with turfgrass diseases, (d)the successful uses of biocontrol agents for plant disease control, (e)the biological traits of *Trichoderma* spp., and (f)strategies for developing effective delivery systems for biocontrol agents for plant disease control.

Turfgrass as a management system

Turfgrasses are plants that form a more or less continuous ground cover that persists under regular mowing and traffic. They are cultured in nearly all inhabited regions of the world(85) and have been recognized for their importance to the quality of life for nearly 2,000 years(81). For instance, they may be used to stabilize soil, provide a cooling effect during warm weather, absorb many toxic emissions from vehicles, serve a decorative function, and provide recreational activities and relaxation(85).

Like most agricultural crops, turfgrasses grow best in well-aerated soils with adequate moisture and nutrients; however, many turfs are subjected to intensive traffic that compacts the soil and causes extensive wear of the turfgrass plants(85). The demand for dense, low-growing turfgrass with rapid recuperative growth ultimately results in small plants that are less tolerant of stress and more susceptible to disease. Reducing the mowing height to achieve higher shoot density requires increased use of fertilizers, irrigation water, pesticides, and cultivation methods. With each additional operation, the potential for reducing tolerance of grasses to pathogens and environmental factors increases along with the number and severity of problems encountered during the growing season(76,85,88). For example, bentgrasses are low-growing, fine-textured grasses that provide high-quality greens for golf courses and bowling clubs. Generally, bentgrasses are very susceptible to diseases and difficult to manage on home lawns because they are adapted only to moderately fertile acidic soils that drain well. Bermudagrass, or couchgrass, is the most widely used warm-season turfgrass. Various species and hybrids are cultured for diverse turf uses, including greens and fairways on golf courses, lawns, and athletic fields, but they are intolerant of dense shade, extremely cold climates, and very wet soil. Fine-textured fescues are used in monoculture or in seed mixtures with *Agrostis*, *Poa*, and *Lolium* spp. They grow well on poor, droughty sites and on acidic soils but not on wet or highly fertilized sites. They have excellent wear tolerance but are susceptible to many diseases(81).

The main diseases of turfgrass

Many important diseases occur in grasses managed as turf. There are five groups of organisms that cause plant diseases: fungi, bacteria, viruses, nematodes, and phytoplasma. Fungi are the most important cause of turfgrass diseases(88). Diseases are sometimes classified into two categories, noninfectious (physiological) and infectious(81), but Vargas(88) prefers to consider noninfectious diseases as injuries. Injury is damage to a plant caused by a noninfectious agent that injures the plant or destroys its aesthetic value. Damage from

hail, lightning, nutrient deficiencies, and fertilizer or pesticide burn are examples of noninfectious plant injuries[88].

Infectious diseases are divided into three groups including foliar diseases, diseases of foliage and roots, and diseases of roots[81]. Among foliar diseases, dollar spot caused by *Sclerotinia homoeocarpa* F. T. Bennett is a serious disease of turfgrass on golf course putting-greens, closely mown fairways, bowling greens, and home lawns. In cool humid and cool subhumid climates, at least six species of low-temperature tolerant plant pathogenic fungi incite snow mold diseases of turfgrasses. These pathogens are *Coprinus psychromorbidus* Redhead & J. A. Traquair (Coprinus snow mold), *Myriosclerotinia borealis* Bubak & Vleugel (snow scald), *Typhula incarnata* Fr. and *T. ishikariensis* Imai (Typhula blight or gray snow mold), *Microdochium nivale* (Fr.) Samuels & I. C. Hallett (pink snow mold), *Acremonium boreale* J. D. Smith & J. G. N. Davidson, and *Sclerotium rhizodes* Auersw. In addition to these diseases, powdery mildew (*Erysiphe graminis* DC.), pink patch (*Limonomyces roseipellis* Stalpers and Loerakker), rust (*Puccinia* spp., *Uromyces* spp.), may occur commonly on turfgrasses [81,88].

Among diseases of foliage and roots, brown patch, (or Rhizoctonia blight) caused by *R. solani* remains a serious disease in the warm humid and warm tropical climatic zones. *Pythium* species, commonly associated with turfgrasses worldwide, cause seed rot, damping-off, root and crown rots, and foliar blight[82]. In particular, Pythium root rot caused by *P. graminicola* has become more prevalent and damaging to seedlings as well as established turfgrass stands on both golf courses and home lawns in recent years[67]. In addition, *Sclerotinia homoeocarpa* may also cause root stunt of turfgrasses due to toxin production although it does not directly infect the roots of turfgrasses[87]. Other diseases including anthracnose (*Colletotrichum graminicola* (Ces.) G. W. Wils.), Bipolaris diseases, Exserohilum diseases, Drechslera diseases, Curvularia diseases, Fusarium diseases, and Southern blight (*Scleriotium rolfsii* Sacc.) are also common fungal diseases of turfgrasses[81,88].

In diseases of roots, the pathogens may sometimes infect the above-ground parts of turfgrasses but do not frequently invade turfgrass leaves. Take-all patch caused by *Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *avenae* (E. M. Turner) Dennis may be most severe during cool, wet years and in poorly drained, irrigated turfs[81,88]. Summer patch caused by *Magnaporthe poae* Landschoot & Jackson usually appears in early summer and becomes more severe during sustained hot weather[88].

There is only one major viral disease of turfgrass, St. Augustine decline, (Panicum mosaic virus or St. Augustine decline virus) and one major bacterial disease, bacterial wilt caused by *Xanthomonas campestris*[88]. Some nematodes may damage turf but usually are limited to warm temperate and subtropical regions [81]. Therefore, the management of fungal diseases is the primary challenge to plant pathologists and golf course managers [88].

The problems of chemical fungicides for controlling diseases on turfgrass

Despite the many achievements of modern agriculture, certain cultural practices have actually enhanced the destructive potential of diseases. These practices include the use of genetically similar crop plants in continuous monoculture, the use of plant cultivars susceptible to pathogens, and the use of nitrogenous fertilizers at concentrations that enhance disease susceptibility[(88)]. Since the turn of the century, plant disease control has become increasingly dependent on fungicides to combat the wide variety of fungal diseases that threaten agricultural crops[(75)].

As mentioned above, the most common turfgrasses such as creeping bentgrass, bluegrass, tall fescue, ryegrass, bermudagrass, carpetgrass, and centipedegrass are highly susceptible to most fungal pathogens[(88)]. Control of these fungal diseases on golf course turf therefore requires very high levels of fungicides[(76)]. For example, fungicide sales are about $400 million annually in the United States, and about $100 million of that is spent on turf applications, with 90% of these applications on golf courses[(88)]. However, repeated applications of fungicides may result in many problems of crop management including fungicide-resistant strains of pathogens, exacerbation of nontarget diseases, and other harmful side effects [(26,63,81)].

Fungi may develop resistance to fungicides following frequent applications. For example, applications of either a mixture of cycloheximide and thiram or triphenyltin hydroxide to tall fescue (*Festuca elatior* var. *arundinacea*) colonized by a strain of *Rhizoctonia solani* resistant to these fungicides can increase the incidence of Rhizoctonia blight[(22)]. Applications of benomyl, thiophanate-methyl, or thiophanate-ethyl to creeping bentgrass (*Agrostis palustris* Huds) colonized by a benzimidazole-resistant strain of *Sclerotinia homoeocarpa* resulted in significant increases in the incidence and severity of Sclerotinia dollar spot[(22,88,91)]. Sanders *et al.* reported that some resistant mutants of *Pythium aphanidermatum* to metalaxyl in the field were also resistant to both metalaxyl and fosetyl-Al in the laboratory[(74)]. Recently, some isolates of *S. homoeocarpa* have developed resistance to demethylation inhibitor fungicides[(37)].

Numerous nontarget effects of fungicides applied to turfgrasses have been documented, such as promotion of nontarget diseases, change in microbial activities and biochemical processes in soil, and decrease in root and/or stem biomass[(65,81)]. Further, nearly 100 examples of fungicide-induced increases in turfgrass diseases have been documented over the past 15 years[(28,34,35,79,81,87,92)]. Nelson[(65)] has summarized the mechanisms of increased disease incidence and severity as follows: (i) the development of fungicide-resistant pathogen strains that may be more virulent than the wild type population; (ii) reduced disease tolerance of host plants; and (iii) the disruption of microbial antagonism that naturally limits the activity of pathogens.

There has been considerable concern that continuous applications of turfgrass

fungicides may detrimentally affect microorganisms responsible for nitrogen cycling in turfgrass ecosystems[65]. This is particularly important to turfgrass managers since nitrogen management is key for optimum turfgrass growth and development. Many types of soil bacteria, actinomycetes, and fungi are responsible for processes such as organic matter degradation, nitrogen transformation, and nitrogen fixation, which have a major influence on plant growth[89]. Thus, if fungicides inhibit any part of the nitrogen cycle, a reduction of soil fertility and of turfgrass quality may occur.

Numerous fungicides have been shown to stimulate nitrification at relatively low concentrations but inhibit it at higher concentrations[5,65,80,89]. Some of the more inhibitory fungicides include thiram, PCNB, anilazine, metalaxyl, triadimefon, and benomyl[65]. It is believed, at least with anilazine and triadimefon, that the inhibitory effect is primarily on species of *Nitrosomonas*, which convert ammonium to nitrite, and not on *Nitrobacter* species, which convert nitrite to nitrate. On the other hand, the inhibitory effect of metalaxyl results primarily from the inhibition of *Nitrobacter* species[65].

The nontarget effects on the denitrification and ammonification processes have been less studied. However, both benomyl and thiram have been shown to be inhibitory to denitrification when applied at high concentrations[89]. At low concentrations, these same fungicides may even be stimulatory. Ammonification processes in soil may be stimulated by application of thiram and quintozene, but inhibited by applications of anilazene, benomyl, or mancozeb [89,90].

Biological control of turfgrass diseases

Biological control is an attractive alternative strategy for the control of turf diseases given the history of fungicides. Recent studies suggest that individual microbial antagonists are capable of reducing the severity of turfgrass diseases [66]. For example, *Typhula phacorrhiza* Fr. reduced the severity of gray snow mold incited by *T. incarnata* Fr. and *T. ishikariensis* Imai[14,59]. Binucleate *Rhizoctonia* spp. reduced brown patch[13] and strains of the bacterium *Enterobacter cloacae* (Jordan) Hormaeche & Edwards have been effective in suppressing dollar spot activity in the field[67]. Similarly, isolates of *Gliocladium virens* Miller, Giddens & Foster have been reported to suppress dollar spot on bermudagrass[51]. At present, *Trichoderma harzianum* strain 1295-22 has been reported to effectively control some turfgrass diseases[60,61]. Therefore, biological control seems to have a promising future in turfgrass disease control.

Types/species of biocontrol agents

Biocontrol of plant diseases involves the use of an organism or organisms to reduce disease. There are many definitions for biological control, however, the basic idea involves a strategy for reducing disease incidence or severity by direct or indirect manipulation of microorganisms

[10,63]. Among microorganisms, the biocontrol agents may be divided into viruses, bacteria, fungi, and nematodes depending on the various pathogens or crops. This section is not intended to be inclusive but to provide examples that are or have been commercially available.

Bacterial biocontrol agents include *Agrobacterium radiobacter* strain 84 for control of crown gall; ice-minus bacteria for control of the ice-nucleation active *Pseudomonas syringae*; *P. fluorescens* (Dagger G™) for control of Pythium damping off of cotton; *P. fluorescens* strain 2-79 for suppression of take-all caused by *Gaeumannomyces graminis* var. *tritici*[20]; *Bacillus subtilis* for seed treatment (Gustafson Inc.); and *Streptomyces* spp. for control of fungal diseases of wheat, cucumber, carnation, and crucifers[20,63]. Fungal agents include *Peniophora* (now *Phlebia*) *gigantea* for control of fatal root rot of pines caused by *Heterobasidion* (*Fomes*) *annosum*; *Trichoderma harzianum* (F-Stop™; now Bio-Trek 22G and T-22 formulations) for control of root diseases of beans, corn, cotton, cucumber, soybean, sugarbeet, and tomato caused by *Pythium* spp., *Rhizoctonia solani*, or *Fusarium* spp.; *Trichoderma viride* for control of damping off, root diseases, and wood decays; *Pythium oligandrum* for suppression of Pythium damping off of cucumber; and *Paecilomyces lilacinus* for control of nematode diseases of citrus[20]. Viral agents include mild tomato mosaic virus for control of tomato mosaic of tomato; mild citrus tristeza virus for control of citrus tristeza of citrus; and mild papaya ring spot virus for control of papaya ring spot disease of papaya[94].

Trichoderma traits

Trichoderma spp. are widely and naturally distributed in soil. Populations of *T. harzianum* and other species of *Trichoderma* are common components of fungal communities of the rhizosphere. *Trichoderma* spp. are also found on root surfaces of various plants[69,70]; on decaying bark, especially when it is damaged by other fungi[23]; and on sclerotia or other propagules of various fungi[27,69]. They frequently are able to grow well as saprophytic competitors of other fungi[28]. For example, some *Trichoderma* spp. have been studied primarily in relation to their ability to displace plant pathogenic fungi such as *Armillaria mellea* from soils in which trees are grown for timber or crop purposes, such as in tea plantations[21]. *Trichoderma* species display strong competitive saprophytic ability mainly due to a relatively rapid rate of mycelial growth and a tendency to recover quickly in soils treated with fumigants such as carbon disulfide. The rapid growth of *Trichoderma* spp. through the soil may be because it is capable of utilizing very low levels of nutrients that are insufficient for the sustained growth of other saprophytic competitors[54].

In order to grow, fungi require sources of carbon and nitrogen, a supply of energy, and certain essential nutrients such as potassium and phosphorus[29]. Many investigations have shown that *Trichoderma* can utilize numerous carbon sources, such as monosaccharides and disaccharides[23];

complex polysaccharides, purines, pyrimidines, and amino acids(68,87); condensed tannins and catechins(6); aldehydes and organic acids(68,69); and even methanol, methylamine, and formate(87). Although ammonium seems to be the most readily utilized source of nitrogen by *Trichoderma* spp. in buffered media(24), other sources of nitrogen, such as amino acids, urea, nitrate, and even nitrite, support abundant vegetative growth(24). This ability to use various energy sources may be due to a wide range of lytic enzymes produced by *Trichoderma*. As a result, it may be relatively simple to find an inexpensive substrate for biomass production or to add organic materials to soils to improve the growth and activity of the introduced agent.

There has also been considerable interest in the effects of environmental conditions on the growth of *Trichoderma in vitro* and the implications of such effects on the ecological distribution of the biocontrol agent in soil(29,69). Some studies indicate that isolates of *Trichoderma* are able to grow in both acidic and alkaline soils. This may contribute to their recolonization ability and also to their wide range of disease control abilities(54). For example, a study in England found that *Gliocladium* (now *Trichoderma*) *virens* parasitized the sclerotia of *Sclerotinia sclerotiorum* over a wide range (10~80%) of soil moisture content at pH5~8(44,54). The ability of *Trichoderma* to grow in higher pH soil (pH 6.7 or slightly higher values) may be associated with the bicarbonate ion (HCO_3^-). Some researchers have reported that the effects of CO_2 on growth are variable and appear to depend on CO_2 concentration and medium pH(23,69). However, other researchers have also pointed out that *Trichoderma* is relatively unaffected by CO_2 levels up to 10%(12,69).

Ahmad and Baker(3) have used the term "rhizosphere competence" to describe the ability of a microorganism to grow and function in the developing rhizosphere. In 1991, rhizosphere competence was defined as the ability of a microorganism applied by seed treatment to colonize the rhizosphere of developing roots(9). This characteristic is useful for biocontrol agents because they protect not only the seed but also the seedling roots. In addition, the increased growth response may be enhanced by this attribute(9).

Rhizosphere competence in *Trichoderma* trains has been known since 1987(3,4), but the mechanisms and nature of this property are not fully known. It is not a common property since only a few rhizosphere competent strains of *T. harzianum* have been found(9,15,78). The attribute has been studied by dilution plating to measure the distribution of the fungus in general portions of roots(3,78). *Trichoderma* spp. are generally not rhizosphere competent because most species do not grow to depths greater than 2~8 cm(3,9). However, several methods for strain improvement have been adopted in antagonistic *Trichoderma* spp.(45). Mutagenesis and protoplast fusion have provided new strains with improved biocontrol capability, rhizosphere competence and/or resistance to fungicides(3,77,78). Ahmad and Baker have found that higher populations of most rhizosphere competent strains were associated with the upper portions of root below the seed(3). The population density

usually decreased on the mid-portion of the roots, and then increased at 6-8 cm below or on the root tip in comparison with central portions[3,77].

Strain 1295-22, a product of protoplast fusion[50,61], may be the most highly rhizosphere competent strain known today. Colonization pattern and root distribution of strain 1295-22 is different from other strains. It maintains a high and consistent population density over the entire root, rather than only at the distal ends of the root[78].

The understanding of the mechanisms of rhizosphere competence is fragmentary. Nearly all studies were performed by R. Baker and his coworkers. The first rhizosphere competent strains were mutants selected for resistance to benomyl[4,8], although benomyl resistance was not absolutely correlated with increased rhizosphere competence[4,8]. Rhizosphere competent mutants have been reported to produce more cellulase than noncompetent wild type strains[4]. Increased extracellular cellulase activity was associated with increased rhizosphere competence[71]. Baker proposed that rhizosphere competent strains were more able than non-competent ones to degrade cellulosic materials on the root-surface, primarily the mucigel layer, and that this ability enabled competent strains to obtain sufficient nutrients for effective root colonization[9]. Enhanced cellulase production by benomyl resistant mutants of *T. reesei* and *T. harzianum* has been suggested to occur as a consequence of altered tubulin, which may confer resistance to benomyl, since benomyl binds to tubulin[71]. The presence of an altered tubulin gene may lead to alterations in the assembly of b-tubulin into microtubules [53,71]. Secretion of extracellular enzymes is dependent upon microtubule-driven vesicular transport, and the data reported by Peterbauer *et al.* support a model of increased or deregulated vesicle flow[71]. Such a phenomenon may result in increased growth rates of fungi since vesicular transport is required for hyphal elongation. Increased vesicle flow would also be expected to result in higher growth rates[71].

The ability to survive on the phylloplane is also a desirable trait for strains of *Trichoderma* used as biocontrol agents against foliar diseases[30]. Spraying conidial suspensions of *Trichoderma harzianum* has been used to control gray mold on fruits and foliage of various crops either alone or in combination with reduced levels or application times of chemical fungicides [30,31,32,41,47]. Migheli *et al.*[64] has reported that *T. harzianum* survived on the phylloplane of tomatoes for 2 weeks, which suggests that this biocontrol fungus may be potentially effective in controlling above-ground diseases of various crops. However, the mechanisms of phylloplane competence are unknown.

Mechanisms of biocontrol in *Trichoderma* spp.

Biological control by *Trichoderma* spp. has been suggested to be due to antibiotic production, competition for nutrients, or mycoparsitism of pathogens [1,69]. Faull and Graeme-Cook[33] suggested that the biocontrol ability of *T. harzianum* may not be linked to antibiotic production

because some fast-growing strains identified as high antibiotic producers from their in vitro test possesed poor biocontrol ability in soil tests, while others with low antibiotic production but slow growth rate fared little better. However, antibiotics combined with hydrolytic enzymes may have an important role in the antagonistic action[75]. Schirmbock *et al.*[75] have observed that *T. harzianum* produces both hydrolytic enzymes and peptaibol antibiotics in vitro and the antibiotics act synergistically with chitinases and β-1,3-glucanase in the inhibition of fungal spore germination and hyphal elongation.

Nutrient competition between pathogen and antagonist may be an important factor in microbial interaction. For example, seed treatment of corn with strain 1295-22 resulted in significant root colonization and a 25% reduction in electrolyte leakage from the root[11]. Reduction in tissue leakage may be an important mechanism for limiting plant diseases by reducing ectotrophic pathogen growth[20], especially if the biocontrol agent is able to intercept metabolites critical for triggering germination of pathogen propagules in soil[48]. Green and Jensen[40] also observed that *T. harzianum* T3, a nonrhizosphere competent strain, could appear on damaged epidermal cells of cucumber roots, and thus implied that the biocontrol ability may be correlated with competition for specific infection sites.

Mycoparasitism may also play a key role in the antagonistic nature of *Trichoderma*, as described in the earlier section on mycoparasitism. Hydrolytic enzymes produced by the genus are thought to be involved in degrading cell walls of pathogens and in penetration for mycoparasitism[16]. But these enzymes also have been demonstrated to effectively inhibit plant pathogens alone and to reduce disease severity[58]. Deacon and Berry[26] speculated whether these enzymes are necessary for the process of mycoparasitism. Particularly, these enzymes are also present within the cell walls of many fungal hosts but in inactive forms behind the extending hyphal tip; they can be released or activated /reactivated by relatively mild treatment [26,38,73]. Therefore, hydrolytic enzymes of fungal hosts may also be involved in the processes of mycoparasitism. Ko and Lockwood[57] demonstrated that autolysis is probably more important than heterolysis in the breakdown of fungal hyphae that are added to soil. Autolysis of vegetative hyphae also occurs in response to critical nutrient stress in aseptic conditions[18] and is the proposed means by which *Sporidesmium sclerotivorum* induces lysis of the sclerotia of host fungi, because this mycoparasite does not excrete a glucanase[2]. Thus it is possible for those inducible enzymes of parasites to break down and utilize those dead fungal hyphae, while the hosts' enzymes contribute (at least in part) to the actual parasitic events [26]. The role of individual hydrolytic enzymes in mycoparasitism may be well demonstrated by genetic analysis.

The necessity of developing systems for successful biocontrol

Biological disease control is a promis-

ing strategy for managing soilborne or airborne diseases in a range of crops[7,20,60,84]. Biocontrol agents differ fundamentally from chemical fungicides in that they must grow and proliferate to be effective[21]. Effective antagonists must be able to become established in crop ecosystems and remain active against target pathogens during periods favorable for plant infection. To be effective, biological disease control depends not only on delivery of suitable biocontrol organisms, but also on methods and strategies for introducing and maintaining populations and activity of the antagonists in association with crops/plants [83]. For example, with field crops, seed treatment with biocontrol fungi[43,46,52] or bacteria[93] appears to be the most feasible method for control of damping-off diseases. Root dips with suspensions of bacteria or fungi offer protection to shrubs or seedlings against selected pathogens[19,56]. Broadcast application or incorporation of solid formulations of biocontrol agents into soils are common methods for controlling several soilborne diseases[36,72].

Conditions for successful biological control

Basically, there are three critical components of biological control systems of plant diseases: (I) effective biocontrol agents, (II) production and formulation methods that give rise to high yields of biomass consisting of efficacious propagules of high viability and stability, and (III) delivery systems that provide a conducive environment to minimize growth of competitive microflora[45,55]. The delivery systems may be the key component because it involves numerous factors for successful disease control. Delivery includes formulations, dosages, timing, and methods of application that may differ among various crops and/or pathogens. For example, if *T. harzianum* is used to treat cucumber seeds and is applied as a slurry, biocontrol efficacy is marginal due to the faster growth of the pathogen than bioprotectant. However, if the organism is applied to the seed in a nutritive base with an inert layer placed over this (double coating), biocontrol efficacy is considerably enhanced because the bioprotectant germinates first by utilizing seed exudates thereby preventing the pathogen from infecting the root. Further, if the seeds are then incubated for a few days at 100% relative humidity, the bioprotectant grows and colonizes the seed surface. Such seed can then be dried and nearly perfect biocontrol can be obtained[44]. Similar excellent results can be obtained with the use of solid matrix priming with fungal or bacterial biocontrol agents[48,49,50]. This treatment that provides sufficient moisture for the bioprotectant growth but not for seed sprouting also markedly enhances the activity of the biocontrol strains to control *Pythium* diseases. In addition to these methods, other strategies to improve temporal, edaphic, or competitive interactions of bioprotectants may also increase efficacy of disease control. Therefore, successful biocontrol requires considerable understanding of the cropping system; disease epidemiology; the biology, ecology, and population dynamics of the biocontrol organisms; and the interactions

among these variables[1,25,42].

A efficient mode for biological control of turf diseases using *T. harzianum* strain 1295-22

The ideal biocontrol strategy attempts to introduce or promote the activity of biocontrol agents only when and where they are needed or are most effective, and minimizes wasteful application of inoculum to nontarget habitats. Delivery systems that are based on physiological and ecological knowledge and that take advantage of the most effective uses of the particular strain are most likely to provide reliable and consistent results. Thus, for effective delivery, we need to consider plant-pathogen-antagonist interactions in terms of time and space.

Dosage for using *Trichoderma harzianum* to suppress the turfgrass diseases.

Chet and Baker reported that the minimal effective dosage of *Trichoderma* spp. was near 1×10^6 cfu/g of soil to control damping off of radish caused by *Rhizoctonia solani*. Lo *et al.*[61] indicated that population levels of $3 \sim 5 \times 10^5$ cfu/g of soil are sufficient to reduce the disease severity of dollar spot, Rhizoctonia brown patch, and Pythium root rot with *T. harzianum* strain 1295-22 in growth chamber tests. In field trials, populations of *T. harzianum* strain 1295-22 with granular applications remained above $3 \sim 5 \times 10^5$ cfu/g of soil, and these levels reduced the initial severity of dollar spot disease relative to untreated plots[61].

Control model of turfgrass diseases and conclusion

Based on the collective results, the strategies for effective control turf diseases using *T. harzianum* strain 1295-22 are to apply granules in the spring to create disease-suppressive soils and possibly enhance plant vigor. *Pythium*, *Rhizoctonia* and *Sclerotinia* are important soil-borne pathogens, and their survival structures in soil serve as primary inoculum. Consequently, suppression of the initial inoculum will be the first step in managing these diseases of creeping bentgrass. This granular application should be followed by monthly spray applications to suppress foliar phases of these diseases. Inhibition of the secondary infection or dissemination of these pathogens is also important for the management of these diseases. Because of the nature of turfgrass ecosystems, these pathogens may be spread from blade to blade when some of them may escape the granule treatment and infect foliage. Monthly spray applications of 1295-22 could provide a second step in protection of turfgrass foliage from attack and prevent these pathogens from initially infecting leaf blades, and also reduce the spread of disease through mowing or other methods of inoculum dissemination. Finally, our results indicate that it will be necessary to apply weekly sprays for highly effective control of these diseases under severe disease situations[62].

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摘　　要

羅朝村　1997　利用木黴菌防治草皮病害　植保會刊 39: 207-225. (台中縣霧峰鄉台灣省農業試驗所植物病理系)

在草皮病害管理中，生物防治可說是一種較無毒性且可減少化學殺菌劑使用的替代物。雖然草皮病害種類繁多，但主要可歸類成眞菌、細菌、病毒、線蟲及菌質等五大類。眞菌是草皮病害中最主要的病原菌，其中在美國及加拿大地區又以腐霉病菌，立枯絲核病菌及菌核病菌引起的病害最普遍。木黴菌 (*Trichoderma harzianum*) 是一深受注目的有益拮抗微生物，目前可防治的對象廣達多種植物病原菌。例如 *Trichoderma harzianum* 1295-22 菌株是一具有根圈纏繞能力且可防治多種植物病害的菌株；目前已有商品化產品問市。根據田間試驗報告顯示，針對腐霉病菌，立枯絲核病菌及菌核病菌引起的病害，要建立一套木黴菌 (*T. harzianum* strain 1295-22) 防治草皮病害的有效傳輸體系，其主要策略包含下面幾個步驟：(一) 先利用粒劑撒佈處理土壤，以便建立抑病土及增加植物活力；(二) 隨後每月噴施孢子懸浮液一次，以抑制葉部時期的病害；(三) 最後，在環境較適合病原菌時每週噴施孢子懸浮液一次，以產生較好的病害防治效果。

(關鍵詞：生物防治、草皮病害、木黴菌、傳輸體系)